

**Key Comparison GULFMET.L-K1.n01**

**Interferometric Measurement of Central Length of Gauge Blocks**

**Technical protocol**

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1. **Document Control**

Version Draft A-20250827. Minor updates to participant data.

Version Draft A-20250922. First draft based on the CCL-K1 protocol.

1. **Introduction**

The metrological equivalence of national measurement standards and calibration certificates issued by national metrology institutes (NMIs) is demonstrated through key and supplementary comparisons organized by the CIPM Consultative Committees or regional metrology organizations in collaboration with them.

In 2024, at the annual GULFMET TCL meeting, it was proposed and agreed upon to have a key comparison on calibration by Interferometric Measurement of Central Length of Gauge Blocks. The purpose of this key comparison is to support new and existing CMC claims for this method.

All participating NMIs will follow standardized procedures using methods and equipment routinely applied in their calibration services, in accordance with the Mutual Recognition Arrangement (MRA).

1. **Organization**
	1. **Participant**

Table 1. List of participant laboratories and their contacts.

|  |  |  |
| --- | --- | --- |
| **Lab Code** | **Institute and address** | **Contact person(s), phone, email** |
| SASO-NMCC(Pilot) | Saudi Standards, Metrology, and Quality Organization (SASO), National Measurement and Calibration Center (NMCC).Riyadh 11471, P.O. Box 3437.Kingdom of Saudi Arabia. | **Shahad Bin Shuqayr**+966 533510677s.shuqayr@saso.gov.sa  |
| UME | TÜBİTAK UME, TÜBİTAK . Gebze Yerleşkesi, Barış Mah. Dr. Zeki Acar Cad. No: 1, 41470 Gebze Kocaeli. TÜRKİYE. |  Damla Şendogdu, (LGB)+90 262 6795000(3552)damla.sendogdu@tubitak.gov.tr  |
| UAE EMI | Masdar City, AbuDhabi,United Arab Emirates. |  Mr. Majed Sultan Al Senaidi+97124066666, +971506684887 m.alsenaidi@qcc.gov.ae  |
| NMIM-SIRIM | National Metrology Institute of Malaysia (NMIM-SIRIM) Lot PT 4803 Bandar Baru Salak Tinggi, 43900 Sepang Selangor, Malaysia. | **Razman Mohd Halim** +603-87781613 razmanmh@sirim.my**Rafidah Rosli** +603-87781614 rafidahr@sirim.my  |

* 1. **Schedule**

The comparison program is scheduled to commence on 1st March 2026 and finish on 17 May 2026. The timetable for each laboratory is given in Table 2.

|  |  |  |  |
| --- | --- | --- | --- |
| **RMO** | **Laboratory** | **Starting date** | **Time for measurement and transportation** |
| GULFMET | SASO-NMCC | 01.03.2026 | 6 weeks |
| EURAMET | UME | 19.04.2026 | 6 weeks |
| GULFMET | EMI | 31.05.2026 | 6 weeks |
| APMP | NMIM-SIRIM | 12.07.2026 | 6 weeks |
| GULFMET | SASO-NMCC | 23.08.2026 | 6 weeks |

* 1. **Reception, transportation, insurance, costs**

The artefacts used in this comparison consist of short and long steel gauge blocks, securely transported in a hard-walled, foam-filled travel case, with each block seated in its designated slot (Figure 1). Some of the shorter gauges are additionally enclosed in a wooden case. Throughout the comparison, all artefacts must be handled only by qualified personnel wearing appropriate gloves to avoid contamination or damage.

Upon receipt of the package, each participating laboratory is responsible for thoroughly inspecting both the external and internal packaging to confirm completeness and to identify any signs of damage. The measurement surfaces of the gauge blocks must be carefully examined for scratches or other defects. Re-lapping or polishing of these surfaces is **strictly prohibited**. The condition of the artefacts upon arrival must be reported immediately to the pilot laboratory and the previous participant using the reporting forms in Appendices A and B.

The pilot laboratory will cover the organizational costs of the comparison, including the gauge blocks themselves, the protective packaging, and shipment to the first laboratory in each circulation loop. Each participant is responsible for arranging and covering the costs of shipping and transport insurance when forwarding the package to the next participant. Laboratories must confirm the current shipping address of the next recipient before completing their measurements to avoid delays.

After completing their measurements, each laboratory must properly repackage the artefacts and apply corrosion protection (using appropriate oil or anti-corrosion paper) to the steel gauge blocks, especially if they will be stored for more than three days. The package must then be shipped using a reliable courier, and shipping details—including the carrier and tracking number—must be communicated to both the pilot laboratory and the next participant. If the packaging is damaged at any point, it must be repaired before re-shipping. If a laboratory or its courier damages any artefact, that laboratory may be held responsible for its replacement at their own expense or through their insurance.

1. **Artefacts**
	1. **Description of artefacts**

The package contains a total of 14 steel gauge blocks, all donated by SASO-NMCC. The gauge blocks have a rectangular cross-section as defined in ISO 3650, though they are not guaranteed to conform to the specifications of any particular grade. The pilot laboratory has inspected the gauge faces and confirmed their suitability for repeated and reproducible wringing. The 10 short gauge blocks (ranging from 1 mm to 100 mm) are primarily drawn from a single set, while the 5 long gauge blocks (with nominal lengths of 150 mm, 175 mm, 200 mm, 450 mm, and 500 mm) originate from a separate set.

Table 3. List of artefacts.

|  |  |  |  |
| --- | --- | --- | --- |
| **Identification** | **Nominal length/mm** | **Expansion coefficient****/10-6 K-1** | **Manufacturer** |
|  | 1.0 | 11.5 |  |
|  | 2.5 | 11.5 |  |
|  | 3.0 | 11.5 |  |
|  | 3.5 | 11.5 |  |
|  | 4.0 | 11.5 |  |
|  | 4.5 | 11.5 |  |
|  | 25 | 11.5 |  |
|  | 50 | 11.5 |  |
|  | 75 | 11.5 |  |
|  | 100 | 11.5 |  |
|  | 150 | 11.5 |  |
|  | 175 | 11.5 |  |
|  | 200 | 11.5 |  |
|  | 450 | 11.5 |  |
|  | 500 | 11.5 |  |

1. **Measuring instructions**

## **Handling the artefacts**

The gauge blocks should only be handled by authorized persons and stored in such a way as to prevent damage. Before making any measurements, the gauge blocks must be checked to verify that their measuring surfaces are not damaged and do not present severe scratches and/or rust that may affect the measurement result. The condition of the blocks before measurement should be registered in the form provided in [Appendix B](#AppendixB). Laboratories should attempt to measure all gauge blocks unless doing so would damage their equipment or damage the gauge. If a gauge block will not wring readily, the participant shall inform the pilot, identifying the affected gauge block and face. No participant shall try to refinish or repair measuring faces by de-burring, lapping, stoning, or any other method. The measurement of the faces concerned shall be omitted if necessary.

Measurements may only be performed using equipment normally used to offer the relevant CMC service. In case of multiple CMC services in this area, only the service/equipment with the smallest uncertainty should be used, unless the pilot and other participants agree to allow additional instruments to be used; in which case, only the results of the instrument/service with the smallest uncertainty may contribute to the KCRV. No other measurements are to be attempted by the participants, and the gauge blocks should not be used for any purpose other than the comparison described in this document. The gauge blocks may not be given to any party other than the participants in the comparison.

The gauge blocks should be examined before despatch and any change in condition during the measurement at each laboratory should be communicated to the pilot laboratory. After the measurements, the gauge blocks must be cleaned and oiled or greased. Ensure that the content of the package is complete before shipment. Always use the original packaging.

## **Traceability**

Length measurements should be traceable to the latest realisation of the metre as set out in the current “*Mise en Pratique*”. Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

## **Measurands**

The gauge blocks shall be measured based on the standard procedure that the laboratory regularly uses for this calibration service for its customers. The “A” surface is the marked measuring face for gauge blocks with a nominal length < 6 mm and the right-hand measuring face for gauge blocks with a nominal length ≥ 6 mm, respectively (see Figure 2).



Figure 2 – Nomenclature of faces

The measurand to be reported is the deviation *e*c of the central length *l*c from the nominal length *l*n of a gauge block. In this comparison the arithmetic mean of the two values for wringing on both faces is considered as representative for *e*c (see equation (1), the superscripts label the face *wrung to the platen*). In cases where only one face could be wrung the corresponding value should be reported as the result.

 with  and  (1)

As an optional auxiliary measurand the difference *d*c of the central lengths measured when the block is wrung to face A and face B, respectively, should be reported according to equation (2). Care has to be taken to use the correct sign.

. (2)

## **Measurement uncertainty**

The uncertainty of measurement shall be estimated according to the ISO *Guide to the Expression of Uncertainty in Measurement*. The participating laboratories are encouraged to use their usual model for the uncertainty calculation. All measurement uncertainties shall be stated as standard uncertainties. The corresponding effective degree of freedom should be stated by the participants. If none is given, ∞ is assumed.

In the report of the measurement technique ([Appendix D](#AppendixD)) the participant should list any relevant CMC claims for the service(s) related to the comparison.

## **Optical phase change and roughness correction**

The position of the plane where light is reflected from a surface depends on the material and surface finish. As the free measuring face of the gauge block and the platen upon which the gauge block is wrung are in general different in both characteristics, a correction has to be applied. It shall be estimated or determined by each laboratory according to the calibration procedure it usually follows for its customers. Participants should state their technique for estimating this correction in [Appendix D](#AppendixD).

## **Reference condition**

Measurement results should be reported for the reference conditions as set down in the standard ISO 3650. Specifically, these conditions include the reference temperature of 20 °C, standard pressure of 101 325 Pa, and the orientation in which the blocks are supported for measurement. For temperature corrections, the linear thermal expansion coefficient provided in this document ([Table 3)](#Table3) should be used.

# **Reporting of results**

## **Results and standard uncertainties as reported by participants**

The measurement results should be communicated to the pilot laboratory as soon as possible, and **within six weeks of the completion of measurements at the latest**. Results that are not reported in a timely fashion may be dropped from the comparison at the pilot’s discretion.

The measurement report form in [Appendix C](#AppendixC) of this document will be sent by e-mail to all participating laboratories as an editable electronic file. It would be appreciated if the forms (in particular the results table) could be completed electronically and returned to the pilot to reduce the need for error-prone retyping of results. In any case, the signed report must also be sent in paper form by mail or electronically as a scanned PDF document. In case of discrepancies, the signed form will be considered to be the definitive version.

When reporting the results of the comparison, each participant should also report the identifier, range, and uncertainty of any existing CMC related to the comparison. This will be used by the pilot when checking whether or not CMC claims are supported by the comparison results.

If the measurement uncertainty reported by a participant is significantly larger than the relevant CMC claim, this should be explained when submitting the results (e.g., air conditioning failure at time of measurements, artefact damage affecting measurements, etc.).

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare a first draft A.1 report on the comparison. This will be circulated to the participants for comments, additions, and corrections.

## **Results reported by the pilot**

The pilot laboratory will measure the gauge blocks several times throughout the comparison to monitor their stability. However, where the pilot laboratory is acting as a participant in the comparison, only the first set of measurements will be used. This applies in particular to the calculation of KCRVs and to the assessment of the pilot laboratory’s CMC claims.

# **Analysis of results**

## **Calculation of the KCRV**

The key comparison reference value (KCRV) will be calculated separately for each gauge block as the weighted mean of the largest consistent subset of participants’ results [M.G. Cox, *Metrologia* **44**, 187 (2007)]. This procedure is recommended by the CCL [J.E. Decker et al, *Metrologia* **43**, L51 (2006)] and its performance in terms of both statistical confidence and statistical power in detecting inconsistent measurements has been confirmed by recent numerical studies [E. Molloy *et al*., *Metrology* **1**, 52, (2021)]. The consistency of the comparison results with their associated uncertainties will be checked using the Birge ratio, also known as the reduced $χ^{2}$.

## **Normalized Errors**

Deviations of individual measurement results will be evaluated using normalized errors *E*n. Two sets of normalized errors will be computed. The first, based on the standard uncertainties and degree-of-freedom estimates reported for the comparison measurements, can serve to support future CMC claims. The second, based on the expanded uncertainties of the participants’ published CMCs (where applicable), can serve to assess participants’ existing CMCs. In both cases, correlations induced by the participants’ contribution to the KCRV will be taken into account [K. Beissner, *Metrologia* 39, 59, (2002)].

## **Artefact instability**

Some steel gauge blocks exhibit long-term changes in length at a roughly constant rate. Since the rate of contraction or extension of the gauge blocks used in this comparison has not been established in advance, it will be determined over the course of the comparison. For each gauge block, the slope of a linear regression to the pilot laboratory’s check measurements will be used to estimate the drift rate and its uncertainty.

Three cases can be foreseen:

1. The linear regression is an acceptable model for the pilot laboratory’s data and the absolute drift rate is smaller than its uncertainty. In this case the gauge block will be considered stable, the KCRV will be a constant value calculated according to the standard evaluation procedure, and the pilot’s additional check measurements will have no influence on the numerical results.
2. The linear regression is an acceptable drift model, and the absolute drift is larger than its uncertainty, i.e., there is a significant drift of the gauge block length. In this case an analysis similar to [Nien Fan Zhang *et al*., *Metrologia* **41,** 231 (2004)] will be followed. This treats the KCRV as a linear function of time, with a slope and an offset. The slope will be determined, as above, by the pilot’s check measurements. The offset will still be calculated as a weighted average over all participants (or the largest consistent subset, if there are outliers).
3. The pilot’s check measurement results and uncertainties are not adequately described by a linear-drift model. In this case the artefact is unpredictably unstable, or the pilot has problems with its measurements. CCL's WG-MRA will be consulted to determine how best to proceed in this case.

Note that the absolute lengths measured by the pilot laboratory have no special importance in any of these scenarios; the pilot contributes to the KCRV as a regular participant through its first measurement. Only the *differences* between the pilot laboratory’s check measurements are used for the determination of the drift rate.

## **Initial assessment of CMC claims**

A given participant’s results will be deemed consistent with their uncertainty claims unless they have at least one result with a normalized error *E*n > 1 *and* the ensemble of their normalized errors fails a $χ^{2}$ or Birge-ratio consistency test at the 95 % confidence level. If the measurement uncertainty is dominated by fluctuating measurement noise that is uncorrelated between gauge block measurements, then a $χ^{2}$ test provides a global assessment of the participant’s performance that takes into account the likelihood of obtaining normalized error *E*n > 1 by chance among the 15 measurements [P. Pedone, *Measurement* **42**, 1469 (2009)]. If there are correlations between a single participant’s measurements for different gauge blocks, typically because of a dominant systematic effect, then the $χ^{2}$ test is not justified, but provided the systematic effect was properly included in the uncertainty budget the resulting normalized errors should be below 1. Participants whose results fail both tests will be contacted by the pilot so that the discrepancies may be investigated. The pilot will not reveal the sign or magnitude of discrepancies until the circulation of Draft A.

## **Correlation between laboratories**

Since this is a comparison of primary measurements, correlations between the results of different NMIs are unlikely. A possible exception is the common use of the recommended thermal expansion coefficients (from [table 3](#Table3)). A correlation will become relevant only when the gauge blocks are calibrated far from 20 °C, which should not be the case. Thus, correlations are normally not considered in the analysis of this comparison. However, if a significant drift is measured in some of the artefacts, correlations between institutes may be introduced by the analysis proposed in section 7.3b and will have to be taken into account.

## **Linking of results to other comparisons**

The CCL task group on linking CCL TG-L will set guidelines for linking this comparison to any other key comparison within CCL for the same measurement quantity.

**Appendix A – Reception of Standards**

|  |  |
| --- | --- |
| To: | Faisal Alqahtani & Shahad Bin ShuqayrSaudi Standards, Metrology, and Quality Organization (SASO), National Measurement and Calibration Center (NMCC).Riyadh 11471, P.O. Box 3437.Kingdom of Saudi Arabiae-mail: f.qahtany@saso.gov.sa & s.shuqayr@saso.gov.sa  |
| From: | NMI: ……………………………… Name: ………………………………Signature: ……………………………… Date: ……………………………… |

We confirm receipt of the gauge blocks for the GULFMET.L-K1.n01 comparison on the date given above.

After a visual inspection:

[ ]  The gauges appear undamaged. Their precise state will be reported along with the measurement results using the inspection form in [Appendix B](#AppendixB).

[ ]  We have detected significant damage, which puts the measurement results at risk. A detailed description of the damage follows. [Include photos and use additional sheets as necessary.]

**Appendix B – Conditions of Measuring Faces**

|  |  |
| --- | --- |
| To: | Faisal Alqahtani & Shahad Bin ShuqayrSaudi Standards, Metrology, and Quality Organization (SASO), National Measurement and Calibration Center (NMCC).Riyadh 11471, P.O. Box 3437.Kingdom of Saudi Arabiae-mail: f.qahtany@saso.gov.sa & s.shuqayr@saso.gov.sa  |
| From: | NMI: ……………………………… Name: ………………………………Signature: ……………………………… Date: ……………………………… |

The following significant surface faults (scratches, indentations, corrosion, etc.) were noted after a detailed inspection of the measuring faces. (Please indicate location of nominal size and/or serial number to identify orientation of face). This form may be printed, annotated, scanned, and emailed to the pilot.

|  |  |  |  |
| --- | --- | --- | --- |
| $l\_{n}$ / mm | A face | B face | Comments |
| 1.0 |  |  |  |
| 2.5 |  |  |  |
| 3.0 |  |  |  |
| 3.5 |  |  |  |
| 4.0 |  |  |  |
| 4.5 |  |  |  |
| 25 |  |  |  |
| 50 |  |  |  |
| 75 |  |  |  |
| 100 |  |  |  |
| 150 |  |  |  |
| 175 |  |  |  |
| 200 |  |  |  |
| 450 |  |  |  |
| 500 |  |  |  |
|  |  |  |  |

**Appendix C – Results Report Form**

|  |  |
| --- | --- |
| To: | Faisal Alqahtani & Shahad Bin ShuqayrSaudi Standards, Metrology, and Quality Organization (SASO), National Measurement and Calibration Center (NMCC).Riyadh 11471, P.O. Box 3437.Kingdom of Saudi Arabiae-mail: f.qahtany@saso.gov.sa & s.shuqayr@saso.gov.sa  |
| From: | NMI: ……………………………… Name: ………………………………Signature: ……………………………… Date: ……………………………… |

**Please complete this form electronically and email to the pilot.**

Date of start of measurements: ……………………………………….

Date of end of measurements: ………………………………….

Results:

*e*c: Central Length Deviation

*d*c: Difference in wringing

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| $l\_{n}$ / mm | Identification | *e*c / nm | *u*(*e*c) / nm | **eff | *d*c / nm | *u*(*d*c) / nm | **eff |
| 1.0 |  |  |  |  |  |  |  |
| 2.5 |  |  |  |  |  |  |  |
| 3.0 |  |  |  |  |  |  |  |
| 3.5 |  |  |  |  |  |  |  |
| 4.0 |  |  |  |  |  |  |  |
| 4.5 |  |  |  |  |  |  |  |
| 25 |  |  |  |  |  |  |  |
| 50 |  |  |  |  |  |  |  |
| 75 |  |  |  |  |  |  |  |
| 100 |  |  |  |  |  |  |  |
| 175 |  |  |  |  |  |  |  |
| 200 |  |  |  |  |  |  |  |
| 450 |  |  |  |  |  |  |  |
| 500 |  |  |  |  |  |  |  |

**Appendix D – Description of the measurement instrument**

|  |  |
| --- | --- |
| To: | Faisal Alqahtani & Shahad Bin ShuqayrSaudi Standards, Metrology, and Quality Organization (SASO), National Measurement and Calibration Center (NMCC).Riyadh 11471, P.O. Box 3437.Kingdom of Saudi Arabiae-mail: f.qahtany@saso.gov.sa & s.shuqayr@saso.gov.sa  |
| From: | NMI: ……………………………… Name: ………………………………Signature: ……………………………… Date: ……………………………… |

**Please complete this form electronically and email to the pilot.**

Make and type of instrument(s)

Light sources / wavelengths used and traceability path:

Description of measuring technique (mention platen material, method for determining phase correction, other corrections applied such as vertical to horizontal corrections, etc):

Temperature measurement method and range of gauge block temperatures during measurements:

Relevant 95 % CMC uncertainty claim for the service(s) related to this comparison topic (if existing) and identifier of the CMC

If the reported uncertainty is significantly higher than that of the related CMC, explanation for the increased uncertainty